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ABSTRACT

This report summarizes the findings of one of fourteen panels that studied progress in space science applications and defined user needs potentially capable of being met by space-system applications. The study was requested by the National Aeronautics and Space Administration (NASA) and was conducted by the Space Applications Board. The panels comprised user specialists drawn from federal, state, and local governments and from business and industry. In this report, the Panel on Uses of Communications explores more than 20 potential new services that can be provided by future satellite communications systems. Such services include improvement in the transmission of information; provision of greater safety to persons and craft at sea, on land, or in the air; location of those in distress; and warning of impending natural disasters. Recommendations are made with regard to mobile communications for use on land and sea, position determination, mineral and energy exploration, and the possibility of using electronic means to assist in mail delivery, and education and health-care experiments. (MH)

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Practical Applications of Space Systems

Supporting Paper 2

Uses of Communications

A Panel Report Prepared for the

Space Applications Board

Assembly of Engineering

National Research Council

SE 021 005

1974 SUMMER STUDY ON PRACTICAL APPLICATIONS OF SPACE SYSTEMS

STUDY DIRECTOR

Jack M. Campbell
President, Federation of Rocky Mountain States
Denver, Colorado

DEPUTY DIRECTOR

Willis Hawkins
Senior Technical Advisor
Lockheed Aircraft Corporation
Burbank, California

Panel on Weather and Climate

George S. Benton (Chairman)
Vice President
Johns Hopkins University
Baltimore, Maryland

Panel on Uses of Communications

Peter C. Goldmark (Chairman)
President
Goldmark Communications Corporation
Stamford, Connecticut

Panel on Land Use Planning

John R. Crowley (Chairman)
Chairman, Colorado Land Use Commission
Englewood, Colorado

Panel on Agriculture, Forest & Range

A. R. Baldwin (Chairman)
Vice President
Cargill, Incorporated
Minneapolis, Minnesota

Panel on Inland Water Resources

Leonard T. Crook (Chairman)
Executive Director
Great Lakes Basin Commission
Ann Arbor, Michigan

Panel on Extractable Resources

William B. Heroy, Jr. (Chairman)
Vice President and Treasurer
Southern Methodist University
Dallas, Texas

Panel on Environmental Quality

Leon W. Weinberger (Chairman)
President, Environmental Quality Systems, Incorporated
Rockville, Maryland

Panel on Marine and Maritime Uses

James J. Reynolds (Chairman)
President, American Institute of Merchant Shipping
Washington, D.C.

Panel on Materials Processing in Space

Winfield W. Tyler (Chairman)
Vice President for Corporate Research
Xerox Corporation
Rochester, New York

Panel on Institutional Arrangements

Harold B. Finger (Chairman)
Manager, Center for Energy Systems
The General Electric Company
Washington, D.C.

Panel on Costs and Benefits

Albert Kelley (Chairman)
Dean, School of Management
Boston College
Boston, Massachusetts

Panel on Space Transportation

Walter F. Burke (Chairman)
Consultant
Corona del Mar, California

Panel on Information Processing & Services

S. Benedict Levin (Chairman)
Executive Vice President
Earth Satellite Corporation
Washington, D.C.

Panel on Technology

Robert K. Roney (Chairman)
Vice President, Space & Communications
Hughes Aircraft Company
Los Angeles, California

(July 1974)

PRACTICAL APPLICATIONS OF SPACE SYSTEMS

Supporting Paper 2

USES OF COMMUNICATIONS

The Report of the
PANEL ON USES OF COMMUNICATIONS
to the
SPACE APPLICATIONS BOARD
of the
ASSEMBLY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

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PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

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*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state, and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, to study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings, and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports, as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee.* National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems.* National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

PANEL ON USES OF COMMUNICATIONS

Peter C. Goldmark (Chairman)
Goldmark Communications Corporation
Stamford, Connecticut

Roy Anderson
Corporate Research and Development Center
General Electric Company
Schenectady, New York

Albert Horley
Office of Telecommunications Policy
Department of Health, Education, and Welfare
Washington, D.C.

Roger G. Mark
Massachusetts Institute of Technology
Cambridge, Massachusetts

William J. Miller
U.S. Postal Service
Rockville, Maryland

Harold B. Morse
Appalachian Regional Commission
Washington, D.C.

Wilbur Pritchard
Bethesda, Maryland

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Siegfried Hieber
European Space Research Organization
Neuilly-sur-Seine, France

Charles C. Joyce, Jr.
Office of Telecommunications Policy
Washington, D.C.

Richard B. Marsten
National Aeronautics and Space Administration
Washington, D.C.

Delbert D. Smith
Madison, Wisconsin

Edward A. Wolff
Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland

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INTRODUCTION

During the 1974 summer study of space applications, the Panel on Uses of Communications reviewed progress since the 1967-68 summer study* in the field of satellite communications. In addition the Panel considered useful services which may be provided by future satellite communications systems.

Many of the recommendations of the 1967-68 study have been accomplished. The commercial utilization of satellite communications systems for conventional communications services, such as those normally provided by U.S. common carriers, has been exemplified to date by five generations of satellites developed by the International Telecommunications Satellite Consortium (INTELSAT), by the development of satellites for domestic trunk services and by the initiation of work on a maritime satellite. While these advances in satellite communication systems during their first decade have been important, a growing appreciation of communications needs, coupled with rapid potential advances in technology, portends an even greater impact of satellite communications between now and the end of the twentieth century.

Basic technology for the first decade of satellite communication systems was developed and successfully demonstrated in the National Aeronautics and Space Administration (NASA) programs involving SYNCOM and the Applications Technology Satellites ATS-1 to ATS-5. The Interim Defense Communications Satellite Program and the American Telephone and Telegraph Company's TELSTAR also made important contributions. Because the level of investment risk has thus been explored and demonstrated to be acceptable, commercial exploitation readily followed, brought direct benefits and resulted in U.S. leadership in international markets related to satellite communication systems and associated ground equipment.

Several important recommendations of the 1967-68 study are still in process of implementation. These include use of multi-channel distribution satellite systems for domestic communications and exploration of the possible benefits of using television with two-way voice communication in the fields of education and health and in information distribution to sparsely populated areas.

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*National Research Council. *Useful Applications of Earth-Oriented Satellites. Reports of the Panels on Points-to-Point Communication* (Panel 7), *Point-to-Point Communication* (Panel 9), *Broadcasting* (Panel 10), and *Navigation and Traffic Control* (Panel 11). National Academy of Sciences, Washington, D.C., 1969.

With regard to future needs, the Panel explored more than 20 potential new services and examined their relative importance, taking into consideration the needs expressed by the Panel on Marine and Maritime Uses, the Panel on Extractable Resources* and other user panels at the summer study. Such services include improvement in the transmission of information; provision of greater safety to persons and craft at sea, on land, or in the air; location of those in distress; and warning of impending natural disasters. Recommendations are made with regard to mobile communications for use on land and at sea, position determination, mineral and energy exploration, the possibility of using electronic means to assist in mail delivery, education and health-care experiments, and the use of satellite telecommunications to enhance the quality of life in rural areas by making available a full range of educational and entertainment programs. Because of the widespread interest in amateur radio services, and because amateur radio performs a public service in times of emergencies, the Panel took into consideration the needs of the amateur radio community to have placed in orbit satellites which it might build.

A number of other useful services appear possible, for which additional study is needed to assess potential benefits and to consider under what institutional arrangements these services might be provided. It must be emphasized that each service does not require its own separate satellite; rather, a few satellites could provide most or all of the services envisioned. Concepts of several such experimental satellite communication systems, which could demonstrate possible new services to potential users, are presented in appendices to this report.

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*Panel on Marine and Maritime Uses. *Practical Applications of Space Systems, Supporting Paper 8: Report of the Panel on Marine and Maritime Uses* and Panel on Extractable Resources. *Practical Applications of Space Systems, Supporting Paper 6: Report of the Panel on Extractable Resources.* Report to the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1975.

NEEDS FOR LAND MOBILE COMMUNICATIONS

There is a large unmet demand for land mobile communications in business, and industry and for personal use. Nearly half a million applications for licenses to operate communications services are filed each year in the U.S. Many licensees operate several mobile terminals. At present mobile services are provided in the VHF and UHF bands where antenna size and propagation losses do not limit performance. However, at these frequencies the bands available for mobile communications are crowded, and there is a severe shortage of spectrum availability. In the centimeter wavelength region of the spectrum, many channels can be provided but technological and environmental difficulties are encountered with antenna size, attenuation caused by rough terrain, reflections from physical structures and the atmosphere. These limitations may be mitigated by use of satellites which radiate sufficient radio frequency power and have antennas of sufficient size to permit communications with small low-power mobile units in industrial and metropolitan areas. Preliminary calculations indicate that 1-watt mobile units, working with a 1000-channel narrow-beam satellite transponder using 1 watt per channel, could provide services which are superior in performance and comparable in cost to those provided by present systems. Some advances in technology would be needed.

The Panel recommends that NASA, in collaboration with the electronics industry, explore the feasibility and the cost of providing mobile centimeter-wavelength satellite communications services within large metropolitan areas of the U.S.

NEEDS OF THE MARINE AND MARITIME COMMUNITY

COMMUNICATIONS

More than 90 percent of present-day ship-to-shore communications are sent by an operator using a telegraph key and the International Morse Code. The transmissions utilize medium or high radio frequencies and are subject to interference and ionospheric disturbances. Delays of hours and even days are frequently experienced in the transmission of a message between a shipping company office and a ship.

Modern vessels represent large capital investments and their operating costs are high. Improved communications may provide substantial benefits arising from more efficient ship operations and better fleet management. In a recent experiment*, voice, teletype, facsimile and slow-scan television communications, as well as position fixing, were provided by satellite daily over a period of 7 months to a 32,000-ton tanker in service between Venezuela and ports on the U.S. east coast. The shipping company concluded that the satellite service offered communications capability better than any presently available to the maritime industry, and that this improved communications could offer significant benefits in the form of improved efficiency of ship operations and management.

In this particular experiment, teletype service was judged to make the greatest contribution to ship operating efficiency. Voice service was found very useful, facsimile somewhat less so and slow-scan television was found to have limited usefulness. It was estimated that if an operational marine satellite communication system providing teletype and voice service were available, this particular ship could be expected to utilize the teletype service about two minutes per day and the voice service about five minutes per day. If facsimile service were also provided, teletype use would decrease to one and one-half minutes per day and facsimile service would be used about four and one-half minutes per day. Although this experience comes from only one specific type of ship, it is believed the results are representative of the type and daily amount of communications required by ships generally. If equipment and operating costs can be kept sufficiently low, satellite communications might result in substantial savings

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*LaRosa, R.M.; Furick, J. W.; King, D.W.; Anderson, R. E.; and Hoffman, H. E., *Experimental Evaluation of Satellite Communications and Position Fixing for Maritime Users*. Joint Final Report, Exxon Corporation and General Electric Company, June 1974.

to the maritime community through timely receipt of ship rerouting information, better coordination in provision of supplies and spares, improved solution of maintenance and engineering problems, and decrease of losses due to storms.

The Panel on Marine and Maritime Uses has estimated that improved wave and weather forecasts derived from and delivered by satellite systems may reduce cargo and shipping losses caused by adverse weather conditions by 5 to 10 percent, a saving of perhaps $25 to $50 million, annually.

As an indication of the size and the market for maritime communications services, it has been estimated* that by 1980 there will be nearly 14,000 vessels (including fishing vessels over 1,000 tons and vessels of all other types over 10,000 tons) of which 10,000 will be at sea on a given day.

Much progress is being made toward providing satellite communications systems for ships. COMSAT plans to launch a maritime communications satellite called MARISAT in mid-1975. Primarily intended for use by the U.S. Navy, it will have 20 teletype channels and one voice channel available to commercial shipping. The European Space Research Organization (ESRO, now the European Space Agency) is preparing a maritime communications satellite (MAROTS) for launch late in 1977. An international conference will be held in mid-1975 to begin work toward an operational international maritime satellite communications system.

POSITION DETERMINATION

As pointed out by the Panel on Marine and Maritime Uses, there exists a number of ground-based radiowave position-determination systems, including LORAN-A (being replaced by LORAN-C), DECCA, and OMEGA. None of the ground-based systems currently provide global coverage because the many land-based terminals needed for such coverage have not been installed. A Navy satellite navigation system (TRANSIT), available for civil use, provides global coverage but its accuracy is limited to about one-half mile and the procedure for using it is complicated and requires relatively costly shipboard equipment. The Department of Defense (DOD) is planning a satellite system (the Global Positioning System or NAVSTAR) which will permit highly precise position fixing, including determination of altitude. The Panel understands that it is the present intent of DOD to make NAVSTAR available for civil use. However, the Panel considers it unlikely that the on-board equipment required to use the system would be sufficiently low in cost to permit very wide use by the marine community.

The existence of several ground-based regional position determination systems results in a dissipation of public and private funds, necessitates carrying aboard ships and aircraft different devices for navigating in various parts of the world,

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*B. A. Mendoza, *et al.* *Maritime Services Satellite System Definition Study.* Final Report of Contract DOT-TSC-98 to U.S. Department of Transportation. (U.S. Document No. PB-204860), Automated Marine International, Newport Beach, California, 1971 and *Maritime Satellites - A Technical and Economic Planning Report for the Initial Maritime Satellite Consortium (IMSCO)* A.M.I. DC-20. Automated Marine International. August 1971.

and wastes valuable segments of the already over-crowded electromagnetic frequency spectrum. The Panel on Marine and Maritime Uses would like to see existing regional systems replaced by a unified and continuously available position determination system of sufficient accuracy (200 m) for maritime navigation in the high seas and in confluence regions. As a goal, such a system should be comparable with or less costly to operate than the present aggregate of systems, and the associated mobile receiving equipment should be economical for the user to lease or own. Such a position determination system providing coverage between about 75° N or 75° S latitude could also be of benefit for ship movement advisory services, for maritime traffic control and for uses other than maritime shipping.

The Panel on Marine and Maritime Uses has estimated that on a typical transatlantic crossing, a 93 km (50 n. mi) saving could result from improved space-based navigation and routing services, and would save 100 barrels of oil per trip. At $11 per barrel for 6 annual round trips for each of the 570 U.S. flag ships, the gross saving would amount to $7.4 million. In the future, a 10 percent saving in time resulting from improved routing for 200,000-ton tankers at $36,500 per ship per day would amount to a gross saving of $525 million for the approximately 400 tankers which (as of June 1974) it is estimated will be needed to deliver oil to the U.S. in 1985.

The Panel concludes that satellite communications and position determination capability should be provided around the globe at an early date in the latitudes presently used by merchant shipping and should be extended to polar regions by the 1980's. The present partially suitable and costly regional navigation systems should be replaced if possible by one widely useful system, inexpensive to use, which may be integrated with the communications system. A large number of shipboard terminals will be needed. To make them less costly and less complex, there is a need for increased emphasis on research and development on spacecraft antennas, on power sources, and on more efficient modulation techniques. It should be noted that the space portion of such future satellite communications and navigation systems may be incorporated in spacecraft which also serve other purposes. It may also be desirable to provide capability for the system to collect data from sensors aboard ships -- for example, data on weather, on the behavior of the ocean or possibly even research data on the structural behavior of the ships.

The Panel believes that the needs for marine communications and position fixing could, for the most part, be met by using presently available technology. Additional research and development is needed, however, to permit selection of techniques and definition of specifications for low-cost operational systems. Research and development on highly reliable minimum-cost equipment is in progress and should be continued. Industry should be primarily responsible for such research and development, with some participation by NASA, the Maritime Administration and maritime users.

It is recommended that NASA's internal R&D program and the R&D program which NASA sponsors in industry continue to emphasize low-cost techniques applicable to the needs of maritime community for satellite communications and position determination. It is also recommended that MARAD continue to coordinate national activities aimed toward providing a single low-cost satellite maritime communications and position determination system.

NEEDS OF THE MINERAL AND ENERGY EXPLORATION COMMUNITY

The extractable resources industry serves a market of $32 billion in providing raw materials and $150 billion in processed materials and energy each year. Exploration for new sources costs from $40,000 to over $1 million per site. With a market of this size and at these costs, exploration crews must be as efficient as possible. According to the Panel on Extractable Resources, mineral exploration teams require position determination accurate to 30 meters in remote locations all over the world. They will need an accuracy of ± 15 m in the 1980's. By the 1980's data transmission at a rate of 10 million bits per second will be needed to send data (for example, seismic data) for processing at a central location.

Satellite communications and position-fixing systems can potentially meet these needs especially in remote regions of the earth. To meet the accuracy and high data rate requirements, some research is needed to better establish the fundamental limitations on measurement imposed by propagation effects and the accuracy with which the position of satellites can be determined. To achieve high accuracy, further development of techniques for controlling the attitude of spacecraft is needed. The service must be usable with man-transportable transmitter-receivers of relatively low cost. To establish the limits imposed on accuracy by propagation requires measurement of propagation delay effects in the ionosphere and troposphere, Faraday rotation, and tropospheric refraction. The measurement techniques involved require coherent transmissions from at least three widely separated frequencies from a spacecraft. ATS-6 is the only satellite presently in orbit that can provide the coherent multiple frequency transmissions.

> *The Panel on Uses of Communications recommends that NASA, in cooperation with other federal agencies as appropriate, perform the technical research and development needed for improving the accuracy of electromagnetic position determination techniques.*

A few systems for multiple use should be adequate if the programs are integrated with other applications. At the present time, however, there is no institutional mechanism by which such common use of systems can be arranged.

> *The Panel recommends that the federal government take the initiative to examine the combined communications and position determination needs of the extractive industries and the maritime community, and determine the possibility of designing an*

integrated system to serve both needs. It is further recommended that the possibility of combining these needs with those of the aeronautical community be considered.

ELECTRONIC MESSAGE HANDLING

The volume of mail in the United States is growing at a rate that creates major problems in delivering mail expeditiously and inexpensively. A great part of the mail involves commercial or routinely printed messages that do not require privacy. Many of these messages could be sent from one postal center to another by electronic means, particularly when long distances are involved. Electronic message delivery could also have implications in education -- for example, in the exchange of library materials, the distribution of instructional materials and newsletters.

The U.S. Postal Service (USPS) is examining the possibility of an economically feasible and marketable electronic message system. In the course of this preliminary system definition study, market research necessary to make a judgment on whether customers want and are willing to pay for this kind of service will be accomplished. In the study, systems using satellite communications, as well as terrestrial communications links, are being considered. If the results of the preliminary study are favorable, a decision could be made to proceed with development and testing of equipment. This later phase would be completed during fiscal year 1979. If it is decided to proceed with a system, it is envisioned that it could be in operation sometime about 1985.

Operation could begin with a relatively simple system which could evolve to more and more automation over a period of time. In the early stages, paper-mail input to an electronic message center might be converted to electronic form by optical-character readers, by graphic scanning, or possibly by a combination of both techniques. Many of the messages suitable for electronic transmission would be expected to originate as business information (for example, bills and invoices) already on electronic tapes and stored in computers. These could be transmitted to electronic message stations by telephone lines or cable or the tapes might be transported to the centers. Business correspondence also could be transmitted electronically, since such messages are usually typed and may be put directly into electronic form by keyboard-to-tape conversion or by graphical-facsimile conversion. Messages destined for distant stations could be transmitted over common-carrier communications networks to destination stations where, still in electronic form, they could be merged and processed with mail for local distribution.

Electronic message centers might evolve as switching centers which could route messages electronically to local post offices for conversion to hard copy for delivery. If terminals sufficiently low in cost can be developed, local post offices also might be able then to switch messages, also electronically,

to a home or place of business for printout on a remote printer. Eventually it may be possible for messages to be transmitted from or received on a terminal at a home or place of business. Thus, messages not requiring privacy would exist only in electronic form within the system and would appear as hard copy only at input and output points.

Nonbusiness messages originating with individuals could also be sent through an electronic system. The procedure could be handled using kiosks located in shopping centers, airports, and post-office lobbies. The kiosks, which would be somewhat like telephone booths, could contain graphic-conversion terminals connected to the electronic message center. Provision could be made for protecting the privacy of communication where it is appropriate.

USPS is being assisted in the preliminary system definition, now under way, by the National Bureau of Standards, the Naval Electronics Laboratory, and the Office of Telecommunications of the Department of Commerce.

The Panel estimates that as much as one-third of today's first-class mail is generated by electronic devices. It seems clear that with the increase which must be expected in the volume of mail, a projection of present practices for handling mail cannot provide either the expeditious postal service that business and the public desire or an economically self-sufficient postal service.

The Panel believes that technologies in communications, input-output devices, computers and information processing memories will be sufficiently advanced to implement an electronic message handling system in accordance with the schedule currently contemplated by USPS. What remains to be established is whether the public needs (or wants) an electronic message handling system, and if so, who should provide it. At present, no organization other than USPS exists with the capability of collecting, handling, and delivering today's volume of mail nor with the potential capability of implementing on a national scale a system of "hard-copy" electronic message handling centers. In the Panel's view, the commercial opportunities are too great for this market to persist as one to be served solely by the USPS. The Panel believes that the USPS should take the initiative in helping to provide a nationwide electronic message handling service, and that the USPS should help seek modifications in the statutes governing private-sector message services so that others may enter the market.

Satellites already existing or planned, such as the Communications Technology Satellite (CTS) or the ATS series, should be used to assess the usefulness of a satellite in an electronic message handling system.

The Panel recommends that the U.S. Postal Service, when and where required, use the assistance of other federal agencies in the definition and planning of an electronic message system.

NEEDS IN EDUCATION

Greater public access to educational services is needed. A need for continuing professional education in the home or business office was identified and judged to be important by the 1967-68 summer study's Panel on Broadcasting.* Many segments of the population need special communications services and satellite technology may make substantial contributions to meeting these needs. Examples are the alleviation of adult illiteracy and the supplementing of high school, community college, and 4-year college courses with high-level audiovisual materials. Interactive terminals could be used in the future, perhaps opening the way for as yet unthought of means of education.

An example of an important problem which can be ameliorated is that of continuing professional education. About 2 million professionals in the U.S. today (for example, educators, attorneys, engineers, and physicians) are faced with a continuous need to update their education. Some states already require that persons in the medical and dental professions re-establish their competence through periodic retraining.

If only 25 percent of the 2 million professionals spent $200 a year for TV educational services, the revenue would be $100 million a year. That amount should be more than adequate to amortize investments and to pay for the educational software. A 4-channel satellite of a size and weight which could be launched by the Titan III launch vehicle could be designed to broadcast directly to home receivers. (A conceptual design for such a system is presented in Appendix B.) The 2.5 GHz equipment already demonstrated experimentally by ATS-6 and its associated surface terminals could be used. Home installations would need a TV receiver, a roof-top antenna 1 meter in diameter, and a frequency converter. Ultimately a 12 GHz 12 channel system might be used to satisfy this need as well as for a wide variety of other purposes such as rural TV, teleculture, and telemedicine. (See Appendix B.) Educational material broadcast for various professions could be viewed in real time by subscribers or could be recorded on video tape for subsequent viewing. The system could also be used for public broadcasting, educational material distribution, and possibly interactive links. Users of the initial 2.5 GHz band would retain the basic TV set and video-tape recorder and would need a new converter and new antenna to operate on the 12 GHz band.

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*_Report of the Panel on Broadcasting_ (Panel 10), 1969.

The Panel notes that the Department of Health, Education, and Welfare-sponsored Health and Education Telecommunications (HET) satellite demonstrations have shown the feasibility of delivering education services over wide geographic areas. However, personnel from all of the educational institutions must be brought into planning and into research and development efforts if satellite communications are to be accepted in the education process. The roles of educational institutions and personnel associated with the institutions will have to be reassessed if communications satellites are utilized. In the past, educational institutions and educators have been reluctant to begin to use new technology.

The success of efforts to improve education is directly related to the quality of the instructional package which includes pretaped and live broadcasting, data transmission, materials distribution, and interactive links. A closed circuit channel may be required for educating and re-educating physicians, nurses, etc. This channel should also have two-way video transmission to permit diagnosis of medical problems of patients as well as diagnosis of educational problems of handicapped children.

NEEDS IN HEALTH CARE

Equal access to health care service is not available for all segments of the population and this problem is receiving increased attention. Inequitable distribution of medical resources will probably persist even if the number of physicians increases. As a result, in recent years considerable interest has arisen in the possible use of telemedicine systems as vehicles for improving access to high quality medical care. Telemedicine systems would be employed in hierarchical organizations of health care in which the physician and patient are separated geographically and these interactions take place over a communication link. In general, such systems include the following components:

A medical center where medical expertise and diagnostic and therapeutic technology and data are concentrated;

Remote terminals where health professionals or paramedical personnel -- who may be located at a fixed site such as a clinic, a village or other remote populated areas -- may enter the system;

A communications link between the remote terminals and the medical center;

A transportation system for use when movement of a patient to a central treatment point is indicated.

For some purposes, telemedical systems would use wide band communications channels. For example, real-time video seems essential for such functions as remote supervision of anesthesia, speech therapy, orthopedic examination and certain critical procedures. Remote radiographic interpretation may be done with slow-scan video systems but there may be an accompanying high cost in professional time and frustration. Continuous two-way wide-band communication is probably not necessary; perhaps the best arrangement is one in which a continuous, two-way narrow-band channel is provided, supplemented by wide-band transmission capacity as needed. Such additional capacity could be supplied by a satellite link which would be made available on a priority basis. Such a system would require sophisticated flexible ground terminal equipment and central data management capability. Its advantage is that the wide-band portion of the system would not require extensive fixed ground-based communications links.

Telemedicine systems have their greatest applicability in rural regions where conventional land-based communications are inadequate or not reliable (for example, in Alaska, Appalachia, the Rocky Mountain area, and some developing countries). In such regions, satellite communications may be the cheapest alternative for providing needed health care. Experience in experimental telemedicine systems has shown that for most primary care settings, narrow-band channels provide adequate communications between physicians in hospitals or clinics and reasonably sophisticated health professionals in a remote area. Such channels can support both consultations and transmission of medical data (for example, medical records and protocols). Experience in Alaska has shown that very significant improvement in health care occurs when reliable two-way audio communications are provided between hospitals and remote villages. High priority should be given to providing the reliable communication on a continuing basis.

Continuation of the current series of Health and Education Telecommunications (HET) experiments on ATS-6 has great value in determining the viability of postulated services. However, after only 9 months of the experiments ATS-6 was moved to serve another commitment. Nine months is not sufficient time to assess the complex social and institutional changes which are involved in experiments of this type. Services provided by ATS-6 are currently perceived as valuable by users served. Termination of the HET program without a plan for follow-up can lead to premature abandonment of a potentially valuable concept and a waste of the federal and regional investment to date.

*The Panel recommends that NASA complete and launch ATS-F' by the time ATS-6 is moved to India so that vital U.S. experiments in education and health care can continue uninterrupted.**

*In July 1974, when the Panel completed deliberation, this option was still open. ATS-F' was the back-up or contingency spacecraft for ATS-F which, when launched, was redesignated ATS-6. This possibility of launching ATS-F' has been foreclosed by termination of the program and "mothballing" of the uncompleted satellite. The Panel still believes and recommends that federal, state, and private support should be made available to permit completion of HET experiments.

OTHER POTENTIAL SERVICES

The Panel has examined a number of services which might be provided through the use of satellite communications. Certain of these services appear to offer substantial potential benefits to the public, and the Panel believes they warrant further study. The most significant are search and rescue, disaster warning, dissemination of time and frequency standards, provision of TV and teleculture to rural areas, collection of data on environment and resources, and wildlife monitoring.

The Panel has not dealt in this report with conventional ground-based communications to meet the needs of business and government because the markets for such services are readily perceived and it is reasonable to assume that private enterprise will move into the markets as they become apparent. It should be noted, however, that studies and experiments are being made, some by government agencies and others sponsored by government agencies, relative to the substitution of communications for travel. Many of the techniques being considered involve television, and satellite communications may be competitive with terrestrial systems in providing the service needed.

SEARCH AND RESCUE

International agreements provide for search for and rescue of survivors of accidents at sea that involve aircraft and ships or boats. The U.S. Coast Guard (USCG) is the lead agency for U.S. participation in such efforts. The USCG is assisted by other federal agencies as appropriate and by many state and local agencies when needed.

Most search activities are conducted visually from ships and aircraft. Effective communication and location by radio can increase the speed, probability of success, and efficiency of Search and Rescue (SAR) parties. However, currently available radio communications are subject to propagation disturbances and interference, and radio location methods are not unified. Furthermore, geographical barriers such as mountains and large expanses of territory inhibit the satisfactory reception of radio signals at some SAR stations as well as in SAR operations. These deficiencies prevent the implementation of a reliable worldwide search and rescue system based on terrestrial radio.

Because of the kind of communications and position determination required and because of the global magnitude of the SAR function, the Panel feels that earth-oriented satellites can play a useful role therein. The USCG estimates

that 400 lives would be saved at sea each year* by the use of satellites to aid SAR. In addition, every year a number of private aircraft downed in mountain or wilderness areas are not found for days or even months. Thus, prompt location and assistance could save much suffering and many lives on land and at sea. Improving SAR operations through the use of satellite systems was included as an urgent need in the 1967-68 study report of the Panel on Navigation and Traffic Control.** The problem has not been acted on as recommended. The present Panel again concludes that the use of satellites to assist in search and rescue operations be given urgent attention.

The use of satellites for SAR would involve the use of small electronic packages which could be turned on, either manually or automatically, when someone is in need of help and which transmit signals via satellite relay to a ground control center. The transmitted signals could provide information on position and on the nature of the problem. The control center can then transmit an acknowledgment signal through satellites to advise that the request for help has been heard.

Several experiments have proven the technical feasibility of using satellites in SAR. The Global Rescue and Alarm Network, which is based on the NASA Orbital Position Location Experiment system, receives OMEGA position signals at very low radio frequencies (VLF) and relays them through a communication satellite to a shore-based monitoring center. The center identifies the party in distress, computes its location, and initiates search and rescue activities. Other experiments have shown that signals from low-power hand-held transmitters can be received by and relayed through geostationary satellites. In one experiment, a simple collapsible helical antenna weighing approximately 1.4 kg (built on the skeleton of a golfer's umbrella) was used with a small commercially available 5-watt transceiver to relay two-way voice and telegraph signals through the very high frequency transponder of ATS-3. It has been shown that the device can transmit telegraph signals through the satellite transponder even though the same satellite transponder is simultaneously relaying a signal from a powerful ground station. The experiment suggests that it may be possible to design a search and rescue system which would include user equipment to be carried routinely and an existing satellite transponder normally used for other purposes (that is, not dedicated to SAR). An appropriate ground-based receiving facility would be required.

The responsibility for designing, implementing and operating a SAR system would appear to be the responsibility of the U.S. Department of Transportation (DOT), of which the Coast Guard is a part. NASA can assist by providing technical advice, assistance with system definition, and experimental links through existing satellites. The Panel believes that once the implementation of a standard system is assured, the electronics industry will perceive a market and design and build transceivers for the users.

The Panel recommends that DOT initiate a study of a satellite-based search and rescue system with a view to determining if the benefits of such a system make it advisable to begin its

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*Baker, James L.: *Satellites for Maritime Applications.* AIAA Paper 73-47, AIAA 9th Annual Meeting and Technical Display, Washington, D.C., 1973.

**_Report of the Panel on Navigation and Traffic Control_ (Panel 11), 1969.

definition and implementation. The Panel further recommends that NASA assist by providing experimental links through existing satellites.

DISASTER WARNING

Early warning of natural disasters could permit taking emergency steps to lessen their impact and possibly to save many lives. Technology is available to implement a disaster warning system. The Panel believes that industry can be expected to develop low cost audiovisual indicators and ground receivers when a standard system is demonstrated and its utility is assured.

Use of satellites for disaster warning requires installation of electronic devices in homes and places of business which can receive warning signals broadcast from satellites. Events that warrant transmission of warnings include severe storms, floods, fires, accidental release of hazardous materials (as from a truck, barge, tank car, or pipeline), and civil-defense emergencies. Upon receipt of the warning, one would tune to a prearranged radio station to receive information on the nature of the disaster and recommended precautions.

Alternatively, the disaster-warning system could use receivers at local power substations or telephone exchanges which would then relay the signal on utility lines to homes. The satellite warning transmission could be coded to alert only the affected geographical area.

Since there does not appear to be a single governmental agency responsible for the design and implementation of a disaster-warning system, the Panel recommends (1) that the Office of Preparedness of the General Services Administration be assigned leadership responsibility for implementation of the proposed system, (2) that NASA provide the satellite portion of the system, and (3) that other government agencies such as the National Oceanic and Atmospheric Administration and the Department of Transportation be given responsibility for implementation and operation of systems to collect and analyze the information required and to define the circumstances under which a warning should be issued.

TIME AND FREQUENCY STANDARDS

Several nations transmit time signals and standard frequencies by ground-based radio. The inherent nature of the propagation process by which radio signals reach a distant receiver is such that signals are distorted or suffer variable delays much of the time, limiting their usefulness. Transmission of signals by satellites using line-of-sight paths could greatly relieve such distortions of received signals, provide reliable reception in regions where signals may now be poorly received and thus add new uses for the service. Service could be provided in two frequency bands: one for general use at a frequency that can be received on conventional home FM receivers; the other at a higher frequency for users with stringent requirements and sophisticated equipment.

Aircraft collision avoidance systems requiring high-stability and high-accuracy frequency sources for time determination are under study by several

organizations. Using a satellite for dissemination of time and frequency standards, if the required accuracy can be provided, could eliminate the need for atomic clocks (at a cost of $10 thousand to $15 thousand each) to be carried on each aircraft. The Panel estimates that for military aircraft and for domestic airlines this gross saving could amount to $100 million.

A single geostationary satellite could provide to users in the western hemisphere time signals, accurate to within a few microseconds, as well as frequency and relative time to an accuracy of the order of one part in 10^{10}. A higher-frequency service at C-band with suitable modulation could provide service to an accuracy of the order of ten nanoseconds in time and one part in 10^{12} in frequency. If satellites in low earth orbits (which do not stay constantly above the same region of the earth) were employed, users who require high accuracy would need knowledge of satellite position and motion relative to the earth's surface and some sophisticated equipment to correct for errors caused by the Doppler effect. The VHF satellite may be additionally useful when environmental, propagation, or other scientific data and information are transmitted by teletype or by voice and interspersed with time signals as is now the case with U.S. and Canadian HF systems.

The National Bureau of Standards has transmitted time signals through ATS-3 and is currently transmitting time signals experimentally through the Synchronous Meteorological Satellite and the Geostationary Operational Environmental Satellite (GOES). The experiments have demonstrated the feasibility and advantages of this type of service. Some research is needed to determine the most useful form of signals because satellite service will allow uses that are not possible with current terrestrially propagated services. It appears to the Panel that the research and system development required should be the responsibility of the National Bureau of Standards and the U.S. Naval Observatory.

The Panel recommends careful study of the possibilities of disseminating accurate time and frequency signals by satellite. The National Bureau of Standards and the U.S. Naval Observatory should be given the responsibility to carry out this task with collaboration from NASA as needed.

RURAL TV AND TELECULTURE

Urban, rural, and energy problems are interdependent. Making the rural U.S. attractive to more people as a place to live and to work should help to solve the problems. Delivery of vocational and health education, entertainment, public affairs, offerings on national TV, and regional and community information to rural homes could be useful. In the early 1930's when electric power was becoming a necessity for rural homes and farms, the Rural Electrification Administration was created to provide them with electric power. Today, telecommunications have become another such common need, and the Panel believes that the full range of informational, educational and entertainment programs could be delivered electronically to our 50 million rural residents.

Extensive cable systems could provide adequate transmission capacity but only at a very high cost to individual users in rural areas, because a high per capita investment would be required to serve areas of low population density. A geostationary communications satellite can provide service to many areas of low population density at a fraction of the cost of cable systems. To assure that the

programs could be received in the maximum number of communities across the country, ground receiving stations have to be of low cost. The Panel believes that this could be achieved. Because the proposed service could attract millions of users, the Panel believes that a home receiver installation developed and designed for this service should be available at a cost under $500.

The proposed rural satellite TV service, in addition to broadcast TV service, could enable rural areas and communities to share in the cultural and entertainment now available in metropolitan centers. Live performances of drama, opera, concerts, and ballet; and museum visits, lectures, meetings, sports events, conventions, and other events could be beamed to the rural TV geostationary satellite, which in turn would rebroadcast these existing programs over the entire country. The program could be shown on large-screen, high-resolution TV projectors in existing auditoriums or theaters or, via short cable distribution systems, in homes. The Panel believes that with modest admission charges at TV theaters and modest charges per program to cable distribution system users, several hundred ground installations could make an operational system profitable. Moreover, the program sources, such as opera, ballet, concerts, etc., which now barely exist on contributions, may become economically solvent.

The Panel recommends further study of rural TV services to establish system concepts, costs, and benefits.

MONITORING OF ENVIRONMENT AND RESOURCES

The use of satellites for transmission of environmental and resources data could involve both the transmission of data collected by satellite-borne remote sensors and the relay of data transmitted from remote earth-based sensors via a communications satellite to one or more ground stations.

If high-resolution images of a relatively large portion of the surface of the earth are needed, data transmission rates as high as 250 million bit per second may be required.

Collection and relay of data by satellites from ground-based *in situ* sensor platforms could encompass a variety of functional needs. For instance, data on slowly varying environmental parameters, such as river flow, need to be sampled no more often than several times daily. For this application, the data rate is low and the platform locations are fixed and known but there may be a need to collect data from tens of thousands of such platforms, some located in areas that would be difficult for frequent human access. Derivation of wind velocity from position data collected by free-floating balloons depends on frequent interrogations and computations. Similarly, ocean currents are computed from frequent successive measurements of the positions of free-floating buoys. Balloon and buoy platforms also can provide *in situ* environmental data.

As has been indicated earlier, data collected by crews prospecting for minerals or petroleum must be relayed to a central data analysis facility with sufficient speed so that geophysical data can be analyzed and interpreted and appropriate instructions can be transmitted to the crews promptly.

Present communications systems, operating and planned, which are designed to relay satellite-borne remote-sensor data can accommodate the anticipated rate of 250 million bits per second only with difficulty. Higher carrier frequencies

would ease this problem. Research and development presently being undertaken on higher frequency systems, including millimeter wave length and laser systems, for future wide-band applications should be continued.

The Panel recommends that NASA continue its research and development program on higher frequency systems, including millimeter wave length and laser systems, for applications which need wider bands.

WILDLIFE MONITORING

To understand how to protect endangered species and to help assure adequate numbers of animals that are important members of the natural food chain, biologists need information on wildlife migration patterns, populations, herd size, physiological changes and habits. In the envisioned use of satellites to help provide this needed information about wildlife, electronic packages would be attached to selected animals and data relayed via a satellite to a ground center.

Electronic packages carried by animals could transmit animal location information derived from OMEGA or a similar navigation system. The package also could include physiological sensors for selected animals to measure parameters of interest to biologists such as respiration rate and EKG. The package should be small, lightweight, and low in power consumption. The satellite system could be similar to that now used for data collection by low-orbiting satellites. Initial experimentation could involve relatively large animals, while research and development (needed to permit very small and light transmitters) is done. Some limited experiments have already been made, and it appears that the ability of satellites to track and to collect data from many small transmitters can make it practical to monitor wildlife physical condition, populations and migratory patterns.

The Panel recommends that a limited number of experiments in wildlife monitoring be undertaken by NASA using existing data collection systems, such as that on ERTS-1, to give the biological community experience in the use of space technology and to provide guidance for the research and development required for future programs.

The Panel also recommends that studies be undertaken by the biological community, with assistance as appropriate from NASA and the Department of the Interior, to ascertain what animals should be monitored and with what priority, to ascertain systems requirements, and to determine costs and benefits.

At frequencies currently used for data collection up-links, interference can be a problem for future low-powered transmitters suitable for carriage by animals.

The Panel recommends that NASA undertake the studies necessary to support adequate international frequency allocations for wildlife monitoring. Such studies should include measurements of the electromagnetic environment from earth orbit for present and potential data collection bands.

AMATEUR RADIO SERVICE

Many amateur radio operators are highly skilled and innovative professional and technical people who use their hobby to test ideas and techniques. A number of them have been led to careers in electronics as a result of interest developed through amateur radio. Amateur radio operations contribute to international understanding and good will and often provide public services in emergencies.

At their own expense, amateurs have built several small satellites that have been carried piggy-back into low earth orbit, giving the amateur radio community the capability for transoceanic VHF voice and code communications for short periods several times each day. Amateur radio satellites at geosynchronous altitude would give amateurs the capability of transoceanic communications at any time, and some amateurs would like to build such satellites. There are no technical impediments to the implementation of geostationary satellite amateur radio service, and it is within the capability of the amateurs to build the required satellite transponder. In the past, the Department of Defense and NASA have provided launches for amateur satellites when spare payload space was available on launch vehicles placing payloads in low-earth orbit. The Panel hopes that if amateurs undertake to build a geostationary satellite, DOD and NASA will be able to find space for it on one of their missions placing other payloads at geosynchronous altitude.

SOME COMMENTS ON
BUSINESS AND GOVERNMENT COMMUNICATIONS

The Panel considered business and government communications as a potential service and on balance it was decided not to treat it as a separate service in this report. The main consideration was the early availability of commercial domestic satellite services with ample capacity for video, voice and data communication. A vital aspect of interlinking business and government operations over long distances is the terminal equipment and the techniques of teleconferencing. Government-funded studies are under way to develop the optimal methods for such contacts, involving video, voice, facsimile, etc., and various combinations thereof to establish how to maximize effectiveness and achieve favorable psychological reactions to the use of these media.

Competing with the domestic satellite systems will be existing terrestrial links. To encourage substitution of telecommunications for travel (and thus save energy), communications satellites with much higher power, permitting the use of low-cost ground equipment, will be required.

In considering the substitution of telecommunications for travel, one must differentiate between individual business trips and mass travel. By mass travel, the Panel refers to the daily commuting of people by automobiles to and from work in our large metropolitan centers. This matter has been studied by HUD's New Rural Society project, resulting in some significant data: about 25 percent of the nation's gasoline is consumed by daily commuting involving one-way distances greater than 20 miles. This consumption could be radically reduced by providing people with an opportunity to live and work in attractive rural communities. (To reach this goal and to apply communications technology in this direction is the object of the New Rural Society project.)

Business travel of industry and government personnel consumes much smaller proportion of the nation's energy supply. Nevertheless, telecommunications techniques (including the use of satellite communications) are worth pursuing. Reducing business travel will not only save a certain amount of energy but will substantially decrease the fatigue of and time expended by the individuals involved. The success of such substitution depends on the effectiveness of the person-to-person or people communications links, compared with face-to-face meetings. The New Rural Society project has for the past two years engaged in studies and experiments in this field. Actual daily application of teleconferencing by business resulted from some of these studies. A nationwide large-scale use through space communications systems, utilizing low-cost ground terminals would considerably accelerate the decentralization of government, business and people. Satellite Systems A and B, described in Appendix B, are

examples of how to obtain such broad-based services. Whether private industry or government should create this facility the Panel is not able to judge.

MULTIPLE-SERVICE SATELLITES

The services discussed earlier in this report would not each require a special or dedicated satellite. Instead, a few multipurpose public service communications satellites could provide the services considered significant by the Panel (and other services as well). Formidable institutional problems will have to be surmounted, however, because some of the services would appropriately be provided by the private sector at a cost to the user, and other services needed by the public but not economically viable (time and frequency signals, for example) would be available only if provided by the government.

In the course of its work, the Panel did a brief system analysis, with the objective of providing at least a preliminary indication of how many satellites might be required, and what their characteristics might be.

Beginning with the needs expressed to the Panel by the several user panels at the study, and taking into consideration the potential services described earlier in this report, the Panel prepared two illustrative matrices. One delineates the characteristics which each potential service would require of a satellite. The second matrix groups the services which have common technical needs, and shows the characteristics of four conceptual satellite communication systems which together could provide the services discussed in this report. The matrices, with some additional discussion, are presented in Appendix A.

Two of the four conceptual systems would not require separate satellites. Instead, the space portion of these two systems could be incorporated into satellites already planned, such as ERTS, NIMBUS, and GOES. (See discussion of Systems C and D in Appendix A.)

The other two conceptual designs would involve satellites able to broadcast directly to community antennas or to receivers equipped with fairly small antennas. One (System A), operating at 2.5 GHz, is intended to provide education, health care, disaster warning, time and frequency signals, and mobile communications services (this satellite could accommodate amateur radio interests as well). The Panel sees the technical possibility of launching such a satellite within about five years if the needs can be aggregrated and verified.

The second satellite (System B), operating at 12 GHz, would provide electronic mail and rural TV and teleculture services, as well as improved services for mobile communications, disaster warning, time and frequency signals and amateur radio. The Panel envisions that System B could be launched several years after System A (that is, in five to ten years) if needed.

The delivery of education services may require a hybrid system that will utilize the satellites indicated for Systems A and B. Such a system would utilize

new or already existing redistribution systems and thus permit maintaining essential characteristics of existing education institutions.

Rudimentary designs for the conceptual Systems A and B are presented in Appendix B.

A concept for using two direct broadcast satellites of the type described as System B to provide television and teleculture to rural areas nationwide is described in Appendix C.

IMPACT OF SPACE TRANSPORTATION SYSTEMS ON SATELLITE COMMUNICATIONS

If the Space Shuttle System provides low-cost transportation to and from earth orbit, substantial economic benefits could be expected from space communications systems carried to orbit by the shuttle. Of particular interest is the projected availability, in the early years of the next decade, of an Interim Upper Stage (the Space Tug) which not only offers the possibility of placing heavy payloads (up to 3,000 kg) into geostationary orbit but also of providing services, such as payload retrieval, that are not possible with present launch vehicles. Both the design and the operation of future communications and position determination satellites would be affected by the new capabilities. Satellites in which the initial stages have modest requirements in power, mass, and size will become candidates for launch by the space shuttle as their coverage expands and as space traffic increases. There is a discernible trend toward more individual access by users to satellite-ground circuits, particularly where data transmission systems need to serve directly individual users instead of relaying information through centralized collection points. The space segment will need to grow in mass and volume if the cost of the ground segment is to be kept within reasonable limits.

Several possible areas of application have a number of common needs and thus may be served by integrated spacecraft systems. Areas of major impact on configuration design include spacecraft reliability (as in systems redundancy) and operational replenishment (as in multiple satellite launches, orbital standby, and payload retrieval).

> *The Panel recommends that future studies of communication satellite concepts consider use of the space shuttle as a baseline payload carrier.*

Typical communications experiments which might be accommodated on Spacelab are:

> Tests of deployability, contour accuracy, and pointing capability of large antennas for spot-beam communications with small ground terminals. Such antennas offer to conserve spectrum by allowing reuse of the same frequency in different geographical areas.

Tests of space laser systems for satellite-to-satellite interconnections, of shuttle-ground communications by relay satellites and of global coverage for other services.

Study of propagation and atmospheric signal distortion phenomena.

Tests of electronic components for communication systems.

In the near future, these experiments will involve tests in the space environment of devices that are feasible and now under development (such as sun-pumped laser and open-envelope tube amplifiers). Moreover, processing of materials in space may make possible new or improved semiconductor materials, which in turn may make feasible such components as advanced microwave devices, laser elements, cold-emission cathodes, and solar-energy converters, all of which could be of great importance in space communications systems.

The Panel feels that efforts should be intensified to perform, on a broad scale, payload analyses and experiment-accommodation studies for the Space Laboratory.

APPENDIX A

MULTIPLE-SERVICE SATELLITES

From initial discussions by the Panel on Uses of Communications, it appeared that a fairly large number of space communication services could be identified which either are imminent because of their feasibility and benefits or are predictable from observation of historical trends and from an examination of users' needs. About 20 different services resulted from a first survey, but were later reduced to the most significant ones.

Starting with this set of baseline services, the Panel considered factors which would influence what services could be combined and served by a single satellite system, such as system configurations, modes of communication, launch vehicle requirements, technical characteristics, and operational/institutional aspects.

To arrive at a systematic presentation and to facilitate interpretation and development of conclusions, the Panel prepared two illustrative matrices (Tables I and II, below). Not being based on detailed system studies, the matrices cannot indicate precise parameters, nor can they present solutions to technical or organizational problems. However, they are intended to assist in assessing common topological features, identifying key technology problems, postulating traffic volumes, showing the impact on the space transportation program, and identifying major problem areas.

Table I classifies 11 selected services according to their network topology and to the type of information carried. It was considered useful to arrange the services in the Panel's view of a descending order of priority.

Network topology is divided into three main classes: point(s)-to-point(s) communications, broadcasting services, and data collection services. Point(s)-to-point(s) communications systems are characterized by a large number of small or medium-sized terminals for two-way operation, but not restricted to identical channel capacities in both directions. For example, in the educational service, where the teaching program is sent over video channels, the return channel may use only narrow-band links. In most cases, these systems do not show a homogeneous configuration, but are a mix of many small user stations and a few large monitoring or program-generating terminals. The figures given indicate typical numbers of terminals and antenna dimensions.

The use of satellite broadcast systems, as considered here, is not limited to the dissemination of public TV programs. Distribution of any form of information either to highly concentrated populations or to users in widely dispersed areas is included. The Panel categorized such services into three major classes:

Service	Network Topology: Point(s)-to-Point(s) No. of Terminals: Small	Point(s)-to-Point(s) No. of Terminals: Medium	Broadcast: Individual	Broadcast: Community	Data Collection: Fixed	Data Collection: Mobile	Position Location	Type of Information: Video	Type of Information: Voice	Type of Information: Data
Mobile [a]	10^4	< 10			50	500	x		x	x
Electronic Mail	3 m 10^5	6 m 125		3 m 10^5				x (facsimile)		x
Education or PBS	x	x	x	x				x	x	x
Health Care	x	x						x	x	x
Rural TV, Teleculture, or PBS			2 m / 6 dB [b] 10^5	3 m / 2.5 dB 10^3				x	x	x
Search and Rescue	10^4	<100				x	x		x	x
Environmental and Resource Data					x	x	x	x (optical)	x	x
Disaster Warning			10^6	10^3			x		x	x
Time and Frequency Standard Distribution			10^6						x	x
Wildlife Monitoring						10^4	x			x
Amateur Radio	10^4							x	x	x

[a] Includes land mobile communications, maritime communications and maritime position determination.
[b] Antenna size / receiver noise figure.

TABLE I NETWORK TOPOLOGY AND TYPE OF INFORMATION CARRIED

broadcasting to individuals (direct home reception), broadcasting to communities, and broadcasting to redistribution systems. All three broadcasting systems, broadcasting to homes, communities, and redistribution centers could become a part of the education delivery system.

No recommendation is given for broadcast services to redistribution centers since it is expected that this service will be provided by the coming generation of domestic communication satellite systems. Ground receiver noise factors are given in decibels (dB).

Data collection systems comprise a large number of widely distributed fixed or mobile ground-based platforms that are interrogated by communication satellites. The dominating requirement comes from environmental and resources services.

A column shows the requirement for position determination of ships and aircraft, of migrating animals, and of points from which warning or distress signals originate.

Finally, the matrix identifies the type of information associated with a particular service.

Table II, Concepts of Experimental Satellite Communication Systems, is the result of grouping the same 11 services into four different combinations of potentially integrated spacecraft payloads. This approach, while not supported by in-depth compatibility studies, is intended to give suggested direction for future efforts.

The objectives are to obtain high economy in orbital space usage and launch costs by integration of similar mission requirements or common technical characteristics into conceptual multipurpose communication satellites. As a minimum set of applicable commonality factors, the first six columns show: the preferred frequency bands (e.g., L-Band, 2.5 GHz, 12 GHz, etc.); the time frame of first implementation of service; the type of orbit (e.g., geostationary, low-inclination polar); the mass in orbit; the typical launch vehicle size (category); and an estimated launch rate (average over system life and including failures).

The Panel recognizes the lack of precision in the information given; nonetheless, it believes that these launch requirements can be used for the development of application mission models in the 1975-1985 time frame.

A separate column shows where Shuttle/Spacelab experimentation is considered necessary in order to improve technologies of certain space systems or qualify new technologies before committing them to automated spacecraft.

The other columns concern the development of technology for spacecraft antennas (large deployable reflectors, multiple beams); on-board power generation; improved attitude control and position keeping; spacecraft transponder (high frequency, high efficiency); ground terminal gain/noise factor-ratio (low-noise receivers); up-link requirements (optimum modulation methods); and ground tracking requirements (low-cost ship terminals).

A last group of parameters marks the need for activities in the fields of propagation (studies of phenomena in different media), spectrum utilization (optimum frequency allocation), and institutional arrangements.

		Space R&D				Ground R&D				Space Shuttle System Experiment**	Propagation and Media	Frequency Allocation	Institutional Problem
	Frequency	Antenna	Power	Stationkeeping and Control	Transponder	Antenna	Uplink Power	Multiple Access	Tracking				
*System A**													
Mobile Communications	L-band									x	x		x
Education or PBS	2.5 GHz					x							x
Health Care	2.5 GHz					x							x
Disaster Warning	L-band												
Time and Frequency	VHF										x	x	
Amateur Radio	UHF									x			
System B													
Mobile Communications	L-band									x	x		
Electronic Mail	12 GHz	x		x	x				x				x
Disaster Warning	L-band								x	x	x		
Time and Frequency	VHF									x	x	x	
Rural TV, Teleculture or PBS	12 GHz			x	x	x				x	x	x	x
Amateur Radio	UHF												
System C													
Mobile Communications	UHF												
Wildlife Monitoring	UHF						x	x	x				
Environment and Resources	UHF								x			x	
Search and Rescue	UHF					x	x		x	x	x	x	
System D													
Mobile Communications	UHF									x	x	x	
Wildlife Monitoring	UHF							x	x	—		x	
Environment and Resources	UHF								x			x	
Search and Rescue	UHF					x	x		x	x	x	x	

* Launch requirements: System A -- 0-5 years to launch; geostationary orbit; mass of 1500 kg; one launch per year via Titan III.
B -- 5-10 years to launch; geostationary orbit; mass of 2500 kg; one launch per year via Space Shuttle System.
C -- 0-5 years to launch; low polar orbit; mass of 200 kg; one launch per year via Scout (piggyback).
D -- 5-10 years to launch; geostationary orbit; mass of 200 kg; one launch per year piggyback.

** Space Shuttle System experiments on propagation and interference useful for all systems.

TABLE II CONCEPTS OF EXPERIMENTAL SATELLITE COMMUNICATIONS SYSTEMS

APPENDIX B

CONCEPTS FOR TWO DIRECT BROADCAST SATELLITES

(See page 41 for a list of symbols used in this analysis.)

Direct Broadcast System at 2.5 GHz (12 cm)

Assume 1 meter antenna diameter	$\Theta_R = 70\,\lambda/D = 8.4°$
Assume 55% aperture efficiency	$G_R = 0.55\,(\pi D/\lambda)^2 = 25.8$ dB
For a 3.5 dB noise figure	$T_R = (F-1)\,290°$
Overall system noise temperature	$T = T_A + (L-1)\,T_O + L\,(F-1)\,T_O$
	$T = 449°$ or 265 dB
Which leads to a receiving figure of merit	$(G_R/T) = 0.7$ dB/°K

A root mean square (rms) signal to unweighted noise ratio of 33 dB is consistent with European Broadcast Union (EBU) requirements and a Television Allocation Study Organization (TASO) "fine" quality picture.

We further assume an RF transponder bandwidth, B, of about 38 MHz and the usual color TV video band, b, of 6.0 MHz.

Modulation factor $m = (B/2b) - 1$ (Carson's rule)
$= 2.17$

The FM improvement factor I is given as

$$I = 3m^2\,(1+m) = 44.8$$
$$I = 16.5 \text{ dB}$$

The required carrier-noise ratio is then given as

$$(C/N) = (S/N) - I$$
$$= 33 - 16.5$$
$$= 16.5 \text{ dB}$$

This is also high enough to provide adequate margin above the FM threshold of 13 dB.

The basic RF link equation is:

$$EIRP = (C/N)\ L_S + L_I + B - (G_R/T) - 228.6 \quad \text{(all in dB)}$$

Space loss:

L_S = 192 dB at 39,000 km and 12 cm $(4\pi R/\lambda)^2$ (earth's radius of 6371 km)

L_I = 2 dB

B = 38 MHz or 75.8 dBHz

$EIRP = 16.5 + 192 + 2 + 75.8 + 0.7 - 228.6$

= 58.4 dBW

For a U.S. time zone coverage of about 2° x 3° the transmit antenna gain is given by

$$G_T = \frac{26{,}000}{\Theta_1 \Theta_2}$$ (This is consistent with 55% efficiency and 70 λ/D beams)

= 36.5 dB (about a 3 x 4 m antenna)

$P_T = EIRP - G_T$ (dB)

= 22 dBW

= 158 watts per channel

Based on the body stabilized RCA Globecom satellite which will provide 120 watts of RF power with eclipse operation in less than 500 kg, and remembering that the weights of travelling wave tubes tend to vary with the square root of the power, it seems reasonable to assume that 4 RF channels of about 150 watts (without eclipse operation) could be provided in less than 1300 kg -- the approximate payload of a Titan III. Careful design might bring the required package within the payload capabilities of Atlas-Centaur. The problem will be helped by a relatively simple transponder and filter structure with only four channels.

Direct Broadcast Systems at 13 GHz (2.5 cm)

Antennas

3 m $\Theta_R = 70 \frac{\lambda}{D} = .58°$

$G_R = .55 \left(\frac{\pi D}{\lambda}\right)^2 = 48.9$ dB

2 m $\Theta = .89°$

$G_R = 45.4$ dB

Receivers (standard receiver) $F_R = 6$ dB, $T_O + 290°$ K

$T_S = T_A + (L - 1)T_O + L (F_R - 1) T_O$

For a line loss of 1 dB and an antenna temperature of 20°K

$T_S = 1190°$

For a "state of the art" but still uncooled receiver

$F_R = 2.7$ dB (This corresponds to a receiver temperature of 250°K.)

$T_S = 410°$

The possible receiver "figures of merit" G/T_S are

	6 dB	2.7 dB
3 m	18.1	22.9
2 m	14.6	19.3

(G/T_S) in dB/°K

The total 12 GHz band available for down link domestic service is 500 MHz wide from 11.7 GHz to 12.2 GHz. We assume a color TV bandwidth of 6.0 MHz and an RF channel of 38 MHz available for deviating the signal.

$$m = \frac{B}{2b} - 1$$

$$m = 2.17$$

The FM improvement (post-detection to pre-detection in the full RF bandwidth) is given by the usual expression

$$I = 3m^2 (m + 1)$$

$$I = 16.5 \text{ dB}$$

The basic RF link equation (in dB) can be written as

$$\frac{C}{N} = EIRP - L_S - L_I - B + \frac{G}{T_S} + 228.6$$

L_S = Space Loss = $\left(\frac{4 \pi R}{\lambda}\right)^2$ = 206 dB at 12 GHz and 39,000 km

L_I = incidental loss = 5 dB (All the atmospheric effects in this single term have been considered together.)

B = 38 MHz = 75.8 dBHz

$EIRP = P_T G_T$

If one assumes 100 watt transmitter power and U.S. time zone coverage, one should make the calculation using an antenna beamwidth of about 2° x 3°. A 2° circular beam will cover an elliptical area of 800 by 1100 n. mi (a U.S. time zone is about 600 n. mi across by 1000 n. mi long). This allows margin for many alterations in the ultimate specific design. The "footprint" of the antenna will flare out more as the satellite location is offset from the central U.S. It probably should be over the Pacific west of California to cause local midnight and satellite eclipse, when it occurs during the equinoxes, to take place in the early morning hours over the U.S. The battery weight will thus be reduced considerably..

$$G_T = \frac{26,600}{\Theta_1 \Theta_2} = 36.5 \text{ dB (good approximate formula for any large reflector)}$$

EIRP = 20 dBW + 36.5 dB = 56.5 dBW

$$\left(\frac{C}{N}\right) = 56.5 - 206 - 5 - 75.8 + 228.6 + \left(\frac{G}{T_S}\right) = -1.9 + \left(\frac{G}{T_S}\right)$$

By tying four of the 100 watt amplifiers together and feeding the output to the appropriate antenna, the entire U.S. will be covered with the national signals.

Earth Station	Receiver (G/T_S) dB/°K	(C/N) dB	(S/N) dB
2 m antenna - 6dB receiver	14.6	12.7	-
3 m " - 6dB receiver	18.1	16.2	32.7
2 m " - 2.7 dB receiver	19.3	17.4	33.9
3 m " - 2.7 dB receiver	22.9	21.0	37.5

The (S/N) column is the sun of the (C/N) value and the 16.5 dB FM improvement. The first case is inadequate in terms of margin over the FM threshold for (C/N) of about 13 dB. These numbers are rms signals to unweighted noise without pre-emphasis. On this basis, the EBU asks for 33 dB and this signal level corresponds closely to TASO "fine" quality.

Widband High-Resolution Case:

If we use two channels we have an effective bandwidth

$$B = 76 \text{ MHz}$$

$$B = 78.8 \text{ dBHz}$$

For the same 100 watt transmitter (we now have two since we will use two channels), we have a greatly improved picture since the (C/N) remains constant (EIRP increases 3 dB while B also increases 3 dB). On the other hand

$$m = 5.5$$

$$I = 27.7 \text{ dB}$$

This represents an excellent picture with any receiver above threshold. If only 100 watts are used for the double bandwidth, then the (C/N) drops 3 dB and only the receivers with a 2.7 dB noise figure make the threshold (2 m and 2.7 dB). Again, the FM improvement is high enough to ensure excellent picture quality.

If wider area coverage is required, the greater transmitter power compensates nicely for the lesser antenna gain when several channels are used. Thus, again combining the outputs of four 100 watt amplifiers and feeding this to the wide angle antenna to cover the entire U.S., a highly acceptable picture will be produced on the ground with a receiver noise figure slightly better than the 2.7 dB.

For the type of ground receiver employed (non-broadcast), the somewhat higher expense would be no problem. It should be noted that two channels would be combined to carry the high-resolution color signals.

LIST OF SYMBOL DEFINITIONS

λ	-	Wavelength
Θ	-	Antenna beamwidth
Θ_1	-	Antenna North-South beamwidth
Θ_2	-	Antenna East-West beamwidth
Θ_R	-	Receiver antenna beamwidth
B	-	Transponder bandwidth
b	-	Video base bandwidth
C/N	-	Carrier to noise ratio
D	-	Antenna diameter
EIRP	-	Effective radiated power (dBW)
F	-	Noise figure (ratio)
G_R	-	Receiving antenna gain
G_R/T	-	Receiving antenna figure-of-merit
G_T	-	Transmit antenna gain (on-board satellite)
I	-	FM improvement factor if (C/N) is above a 13 dB threshold
L_S	-	Space loss - given as $\left(\frac{4\pi R}{\lambda}\right)^2$
L_I	-	Incidental loss and atmospheric attenuation
m	-	Modulation factor
P_T	-	Transmitter power (on-board satellite)
R	-	Distance from satellite to terrestrial receiver (about 39,000 km in continental U.S.)

S/N	-	Signal to noise ratio
T_A	-	Antenna temperature
T_O	-	Room temperature, i.e., 290° K
T_R	-	Noise temperature of receiver only
T_S	-	System noise temperature

APPENDIX C

CONCEPT FOR A NATIONWIDE SATELLITE COMMUNICATIONS SYSTEM TO SERVE RURAL AREAS

To fulfill the need to make rural America attractive for more people and to deliver to the home continuing vocational and health education as well as regional and community information, in addition to the entertainment and public affairs offerings on national TV, the Panel offers a concept of a synchronous communications satellite system consisting of two identical satellites, each with fourteen 40 MHz TV transponders each with 100 watts output. Typically, the total of 28 transponders can be utilized as follows. On Satellite I, three 400 watt high-power signals are produced by combining 4 output stages for each of three national TV channels corresponding to the commercial networks. These three TV signals, each 40 MHz wide, are fed to the same antenna, covering the entire U.S. Two more channels on the same satellite serve regions I and II, approximately corresponding to Time Zones I and II, counting from the West. Satellite II has two national broadcast channels, again each combining the output from four 100 watt transmitters. One of these channels could be assigned to the Public Broadcast Service and the other to cable networking or for educational-health care services. Of the remaining six 100 watt transmitters, two serve Time Zone III and four broadcast to Time Zone IV (East Coast of the U.S.). This makes it possible on the average for 6 states to share one transponder. Thus, within a given region or time zone, each state can have a one-sixth share of a broadcast day to transmit pertinent local or regional information which can be received everywhere within the zone. Each satellite would have two antennas, the smaller one taking the broadcast feeds covering the entire nation, and the large antenna serving the individual zones.

Figure I illustrates the above and also the number of 40 MHz channels transmitted by the two satellites. The twelfth 40 MHz channel, namely F_6, is reserved to be combined with F_5 providing an 80 MHz wide special broadcast channel for the high-resolution color TV signals for theater projection discussed under "Teleculture."

Regarding reception, it is estimated that a two-meter antenna, together with a 250° receiver and using a parametric amplifier at room temperature, will provide commercially acceptable pictures anywhere in the U.S.

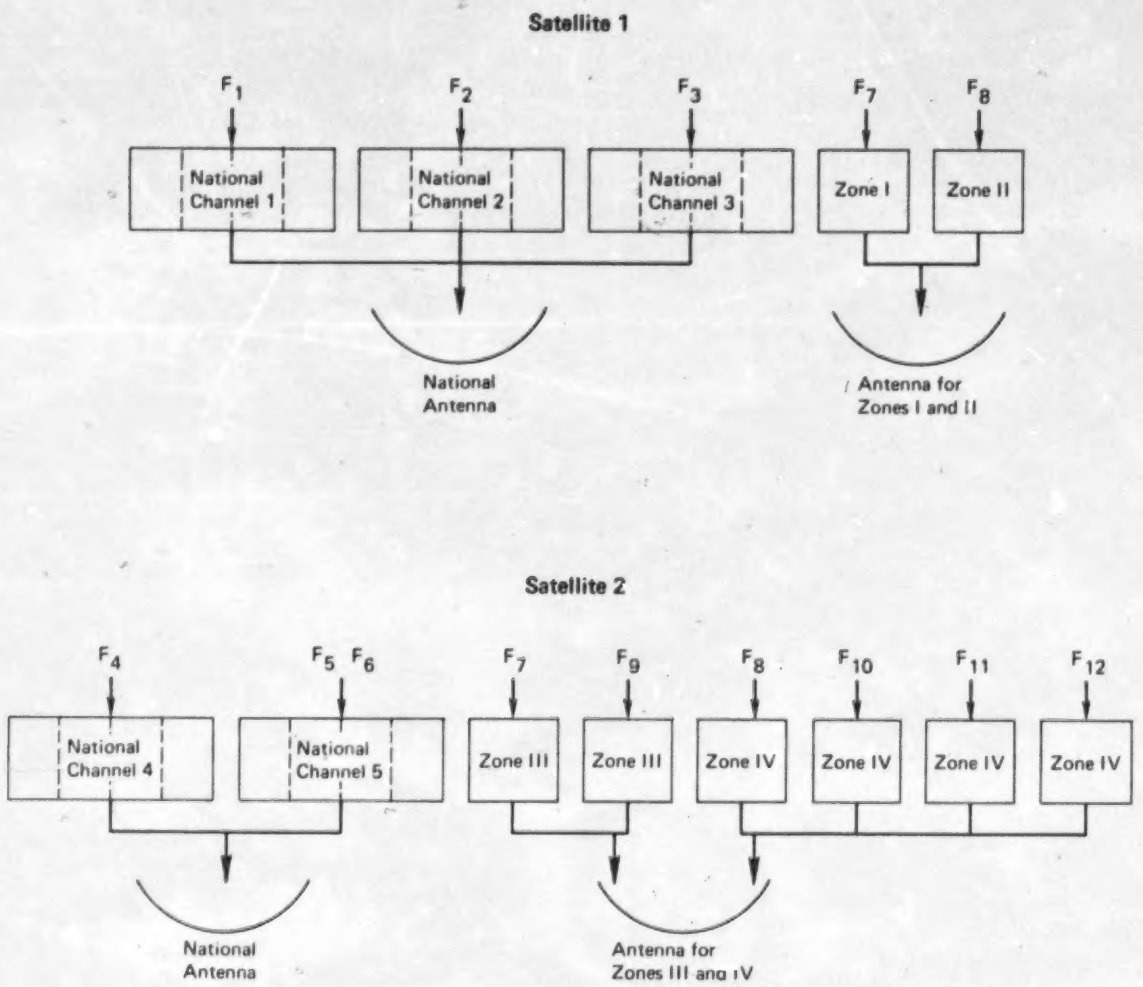

FIGURE I: CONCEPTS FOR SATELLITE RURAL TELECULTURE

OTHER SERVICES IN SYSTEMS A AND B

System A in Table II (p. 34) uses a geostationary satellite that should be launched within five years to provide services for mobile communications, education, health care, disaster warning, time and frequency dissemination, and amateur radio.

The satellite would have an L-Band transponder to provide the mobile communications service. It would have a 2.5 GHz transmitter (6 GHz receiver) to provide professional education and audio-visual technical material distribution for the education, medical and other professional communities. Disaster warning experiments would be undertaken using the 2.5 GHz transmitter (6 GHz receiver). Experiments in time and frequency dissemination could be performed using a UHF transmitter for home reception and a higher frequency transmitter for the high accuracy commercial service. Signals for both services would emanate from an atomic clock. A separate UHF transponder would be included to serve the amateur radio operators.

The mobile communications service would operate with the shipboard and aircraft systems now being built for experimentation with ATS-6 and MARISAT.

The system would provide education and health care services to as many as 100,000 ground stations having one-meter diameter antennas and receivers with a 3.5 dB noise figure at 2.5 GHz. There would be one video channel for each time zone.

Studies will be needed to develop the systems specifications for all these services and for the appropriate experiments for the disaster warning, time and frequency, and amateur radio services.

Attention will also be needed to the design of the software and organizational arrangements for the delivery of these services, so they can be implemented on a total system basis.

System B in Table II uses a geostationary satellite that should be launched in five to 10 years to provide services for mobile communications, electronic mail, rural areas, disaster warning, time and frequency dissemination and amateur radio.

The satellite would have an L-Band transponder to provide the mobile communications service. It would have a 12 to 14 GHz transponder for pre-operational testing of an electronic mail service and for the distribution of video programs to rural areas. An operational disaster warning service could be implemented using the 12 to 14 GHz transponder or the equipment developed for System A. An operational time and frequency dissemination service would be provided by equipment similar to that developed for System A but with improved accuracy. The amateur service could be served with a UHF transponder similar to that used on System A, with a higher-frequency transponder, or both.

The mobile communications service would operate with as many as 10,000 terminals that are compatible with the mobile terminals used for System A.

The electronic mail service would operate with six-meter diameter antennas at the 125 major postal distribution centers and with as many as 100,000 three meter diameter antennas at local post office and commercial business offices. This service would use the space and ground technology presently being developed for the CTS satellite.

The rural area high-resolution color television service would furnish signals to approximately 1,000 community receivers with three-meter diameter antennas and 250° K noise temperature receivers. These terminals would provide a particularly high quality 735 line color TV service for the broadcast of cultural and sporting events programming which could be shown on large screens, in auditoriums.

Details of the disaster warning and time and frequency services will require further study based on the experience obtained from System A.

Consideration should be given to the use of the Space Transportation System to place the satellite in geostationary orbit.

System C uses a satellite in low polar orbit that should be launched within five years to provide data collection and position determination capabilities for the mobile, wildlife monitoring, environment and resource data, and search and rescue services. This system could be implemented on a presently planned satellite such as ERTS-C.

The position determination capability would be based on the use of the OMEGA navigation system to provide an accuracy of $\pm$ 2 km for relatively coarse requirements and an order of magnitude better accuracy where a differential OMEGA implementation is possible.

The data collection capability would be based on the random access technique now being implemented on NIMBUS-F.

The search and rescue service would use an adaptation of the Global Rescue and Alarm Net system.

Studies are required to determine the appropriate methods of providing more accurate position determination information (including the use of NAVSTAR) and to determine the number of data collection platforms to be served.

System D uses a geostationary satellite to be launched in five to 10 years to provide data collection and position determination capabilities for the mobile, wildlife monitoring, environment and resource data, and search and rescue services. This system could be implemented on a presently planned satellite such as GOES.

The geostationary capability is particularly important for applications, such as search and rescue and high data rate continuous data relay, that require good temporal coverage.

More detailed studies of the requirements of the various services are needed for a more complete description of System D.

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